

2

Report No. NADC-90006-60

AD-A225 716



DTIC FILE COPY

DESIGN AND DEVELOPMENT OF A COMPOSITE BATTERY BOX FOR CORROSION CONTROL FOR MARINE CORPS VEHICLES

J.J. Reilly and L.J. Buckley, Ph.D.
Air Vehicle and Crew Systems Technology Department (Code 6064)
NAVAL AIR DEVELOPMENT CENTER
Warminster, PA 18974-5000

J.E. Merritt and C.R. Avletti
A & M ENGINEERING, INC.
Silver Spring, MD 20904

1 NOVEMBER 1989

FINAL REPORT
Period Covering October 1988 to October 1989
Task No. C00760000
Work Unit No. 881135
Project Element No. 26624N
Project No. C0076

DTIC
ELECTE
AUG 23 1990
S B D
Ct

Approved for Public Release; Distribution Unlimited


Prepared for
MARINE CORPS DEVELOPMENT AND EDUCATION COMMAND
Quantico, VA 22134

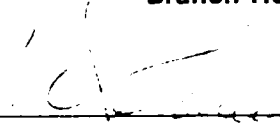
NOTICES

REPORT NUMBERING SYSTEM — The numbering of technical project reports issued by the Naval Air Development Center is arranged for specific identification purposes. Each number consists of the Center acronym, the calendar year in which the number was assigned, the sequence number of the report within the specific calendar year, and the official 2-digit correspondence code of the Command Officer or the Functional Department responsible for the report. For example: Report No. NADC-88020-60 indicates the twentieth Center report for the year 1988 and prepared by the Air Vehicle and Crew Systems Technology Department. The numerical codes are as follows:

CODE	OFFICE OR DEPARTMENT
00	Commander, Naval Air Development Center
01	Technical Director, Naval Air Development Center
05	Computer Department
10	AntiSubmarine Warfare Systems Department
20	Tactical Air Systems Department
30	Warfare Systems Analysis Department
40	Communication Navigation Technology Department
50	Mission Avionics Technology Department
60	Air Vehicle & Crew Systems Technology Department
70	Systems & Software Technology Department
80	Engineering Support Group
90	Test & Evaluation Group

PRODUCT ENDORSEMENT — The discussion or instructions concerning commercial products herein do not constitute an endorsement by the Government nor do they convey or imply the license or right to use such products.

Reviewed By:  Date: 6/7/90
Branch Head

Reviewed By:  Date: 6/7/90
Division Head

Reviewed By:  Date: 6/20/90
Director/Deputy Director

REPORT DOCUMENTATION PAGE				Form Approved OMB No 0704-0188	
1a REPORT SECURITY CLASSIFICATION Unclassified			1b RESTRICTIVE MARKINGS		
2a SECURITY CLASSIFICATION AUTHORITY			3 DISTRIBUTION / AVAILABILITY OF REPORT Approved for Public Release; Distribution is Unlimited		
2b DECLASSIFICATION / DOWNGRADING SCHEDULE			5 MONITORING ORGANIZATION REPORT NUMBER(S)		
4. PERFORMING ORGANIZATION REPORT NUMBER(S) NADC-90006-60			5 MONITORING ORGANIZATION REPORT NUMBER(S)		
6a. NAME OF PERFORMING ORGANIZATION Air Vehicle and Crew Systems Technology Department		6b OFFICE SYMBOL (If applicable) Code 6064	7a. NAME OF MONITORING ORGANIZATION		
6c. ADDRESS (City, State, and ZIP Code) NAVAL AIR DEVELOPMENT CENTER Warminster, PA 18974-5000			7b ADDRESS (City, State, and ZIP Code)		
8a NAME OF FUNDING / SPONSORING ORGANIZATION MARINE CORPS DEVELOPMENT AND EDUCATION COMMAND		8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER		
8c. ADDRESS (City, State, and ZIP Code) Quantico, VA 22134			10 SOURCE OF FUNDING NUMBERS		
			PROGRAM ELEMENT NO 26624M	PROJECT NO C0076	TASK NO C00760000
					WORK UNIT ACCESSION NO 881135
11 TITLE (Include Security Classification) Design and Development of a Composite Battery Box for Corrosion Control on Marine Corps Vehicles					
12 PERSONAL AUTHOR(S) See Reverse Side					
13a TYPE OF REPORT Final		13b TIME COVERED FROM 10/88 TO 10/89		14 DATE OF REPORT (Year, Month, Day) 1989 November 30	
				15 PAGE COUNT	
16 SUPPLEMENTARY NOTATION					
17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	Fiberglass/Epoxy Chemical Resistance		
			Composites Corrosion Control		
			Battery Box		
19 ABSTRACT (Continue on reverse if necessary and identify by block number)					
<p>A fiberglass/epoxy composite material and the vacuum bag molding process were used to replace an existing steel battery box for the Marine Corps MK-48 ground vehicle. This item has been plagued with corrosion problems that directly impacts operational readiness, reliability, and life cycle costs. Quality control, chemical resistance, and mechanical tests were performed after selection of an appropriate material and process. Design and fabrication of several battery boxes has shown a weight savings of 13.2 kg (29.1 lbs). Six composite battery boxes were delivered to the Marine Corps (Quantico, VA) for field testing.</p>					
20 DISTRIBUTION / AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT <input type="checkbox"/> DTIC USERS			21 ABSTRACT SECURITY CLASSIFICATION Unclassified		
22a NAME OF RESPONSIBLE INDIVIDUAL Leonard J. Buckley			22b TELEPHONE (Include Area Code) (215) 441-2823		22c OFFICE SYMBOL 6064

DD FORM 1473, JUN 86

Previous editions are obsolete.

S/N 0102-LF-014-6603

SECURITY CLASSIFICATION OF THIS PAGE

Unclassified

Block 12

J.J. Reilly and L.J. Buckley, Ph.D.
Air Vehicle and Crew Systems Technology Department (Code 6064)
NAVAL AIR DEVELOPMENT CENTER
Warminster, PA 18974-5000

J.E. Merritt and C.R. Avletti
A & M ENGINEERING, INC.
Silver Spring, MD 20904

CONTENTS

	Page
FIGURES	iv
TABLES	v
ACKNOWLEDGEMENTS	vi
INTRODUCTION	1
SELECTION OF MATERIALS AND PROCESS	1
DESIGN OF COMPOSITE BATTERY BOX	8
COMPOSITE FABRICATION PROCESS	8
EXPERIMENTAL PROCEDURE	10
DENSITY, FIBER VOLUME FRACTION, AND VOID CONTENT DETERMINATIONS	10
CHEMICAL RESISTANCE TESTING	10
MECHANICAL TESTING	10
RESULTS AND DISCUSSION	11
DENSITY, FIBER VOLUME FRACTION, AND VOID CONTENT	11
CHEMICAL RESISTANCE PROPERTIES	12
MECHANICAL PROPERTIES	12
COMPOSITE BATTERY BOX EVALUATION	12
CONCLUSIONS	13
RECOMMENDATIONS FOR FUTURE WORK	13
REFERENCES	15

Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	



FIGURES

Figure		Page
1	Photograph of Existing Steel Battery Box	2
2	Photograph of Existing Composite Battery Box Lid	3
3	Diagram of Battery Box Assembly	4
4	Vacuum Bag Molding Process	5
5	Chemical Structures of an Epoxy Resin and Curing Agents	7
6	Detailed Drawing of the Composite Battery Box	9
7	Photograph of the Newly Developed Composite and Existing Steel Battery Boxes	14

NADC-90006-60

TABLES

Table		Page
1	Chemical Resistance Data For Typical Epoxy and Unsaturated Polyester Resins	6
2	Weight Percent and Density Data For Green Dye	11

ACKNOWLEDGEMENTS

The authors wish to thank the U.S. Marine Corps for their financial support. In particular, the authors wish to thank Major Ken Williams for initiating this program and Capt. Kevin Burns for continuing it. The authors also wish to thank the following people for their contributions to the program:

Mr. Sydney Oliver	Ultrasonic Inspection
Mr. Elmer Lion	Chemical Resistance
Mr. Bernard Duffy	Flexure Testing
Mr. Dickson Alley	Specimen Preparation
Mr. James Katilaus	Density, Ignition Loss
Mr. Steve Kolasar	Tensile Testing

INTRODUCTION

Military vehicles are confronted by extremely corrosive environments that can adversely affect their performance. The operational readiness, reliability, and life cycle costs associated with these vehicles are significantly impacted by corrosion. Considerable efforts are expended each year on corrosion maintenance labor and materials to preserve and extend the life of these vehicles. Other sizable efforts are performed to develop and design these vehicles with inherently corrosion-resistant materials to reduce the amount of maintenance required while in service. The work described in this report relates to these latter efforts.

Corrosion of ground vehicle battery trays and compartments has been a particularly serious problem in the Marine Corps. The typical battery used by the Marine Corps is the lead-acid type having a sulfuric acid electrolyte. The battery case and its adjacent areas continue to be subject to the corrosive action of the electrolyte despite protective paint systems and drain hole provisions. Fumes and spillage of battery acid solution initiates and accelerates corrosion of these metallic parts, necessitating their repair or replacement. In particular, the steel battery box on the Marine Corps MK 48 ground vehicle has been very susceptible to corrosion attack. Figures 1 and 2 show photographs of the existing steel box and the existing composite lid, respectively. Also, a diagram of the battery box assembly is depicted in Figure 3.

The specific approach selected was to substitute the steel box with a polymer-matrix composite. Several suitable polymeric matrices and reinforcement fibers can be used to fabricate corrosion resistant battery compartments and trays. The candidate material, however, in addition to being chemically resistant to sulfuric acid (H_2SO_4), must be resistant to gasoline, hydraulic fluid, engine oil, and salt water. Service temperatures ranging from $-40^{\circ}C$ to $60^{\circ}C$ ($-40^{\circ}F$ to $140^{\circ}F$) and mechanical loadings as high as 113 kg (250 lbs) of static force on the battery case cover are also requirements that are to be integrated into the replacement battery box design. The materials and process are to be selected to minimize costs when the box moves into production.

SELECTION OF MATERIALS AND PROCESS

The initial step in designing a corrosion-resistant battery box is to select a material system and a processing technique that will meet both the mechanical property and chemical resistance requirements in a cost-effective manner. Various processing techniques such as injection molding, compression molding, stamp molding, resin-transfer molding, contact molding, pressure-bag molding, vacuum bag molding, etc., were considered for this application. Injection molding, compression molding, and stamp molding were each eliminated due to the relatively high tooling costs associated with these processes. Note that the tooling cost was a major factor since low production volumes were anticipated. Resin-transfer molding and contact molding were not considered because of their limitations on fiber content (typically less than 35% by weight). This left pressure bag molding and vacuum bag molding as processing candidates. Both of these processes utilize single mold, composite tooling (either male or female), are amenable to room-temperature curing, and allow high fiber fractions for good mechanical properties. Both processes are also very similar. However, the tooling cost associated with pressure bag molding is slightly higher than that of vacuum bag molding because the tooling must be strong enough to withstand the applied pressure. For this reason, the vacuum bag molding process was selected. A diagram of vacuum bag molding is shown in Figure 4.¹

After the process was selected, it was necessary to select the specific material system. The three generic resin systems primarily used in vacuum bag molding are polyesters,^{2,3} vinyl esters,^{2,3} and epoxies.^{4,5} However, the Marine Corps⁶ requested that the final material meet a military specification. This factor was included to facilitate future composite battery box procurements. It was learned that

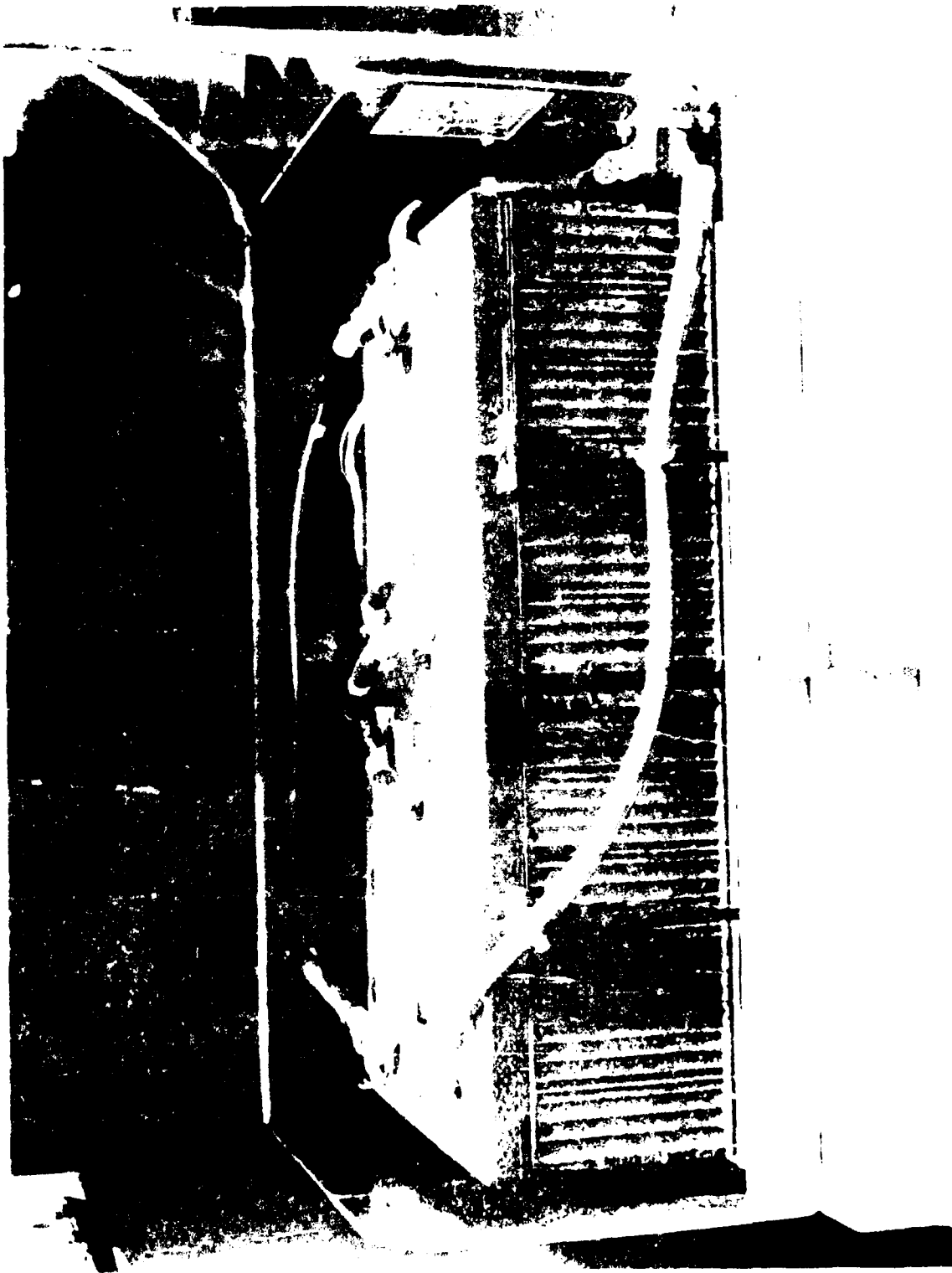


Figure 1 Photograph of Existing Steel Battery Box.

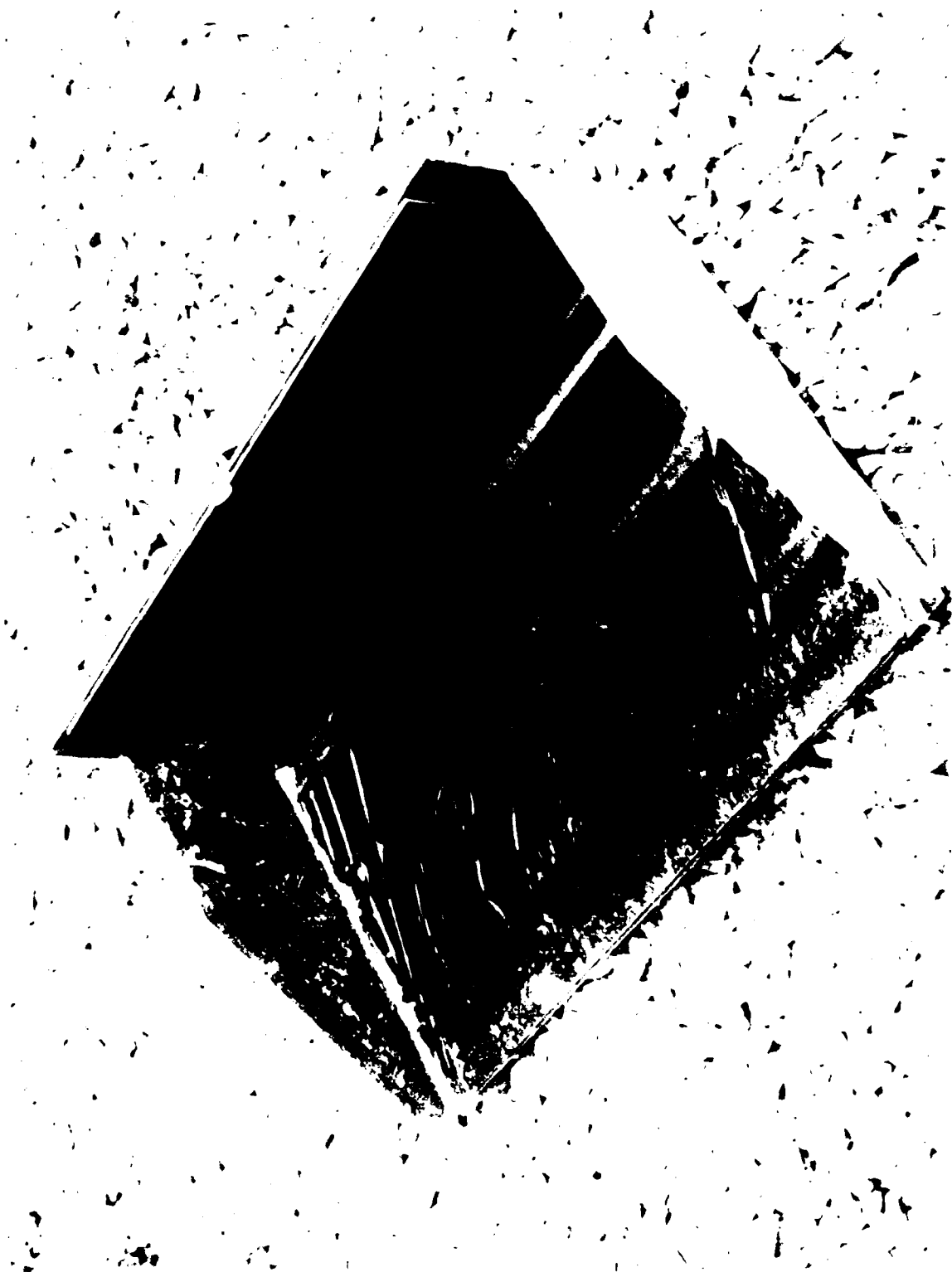


Figure 2. Photograph of Existing Composite Battery Box Lid.

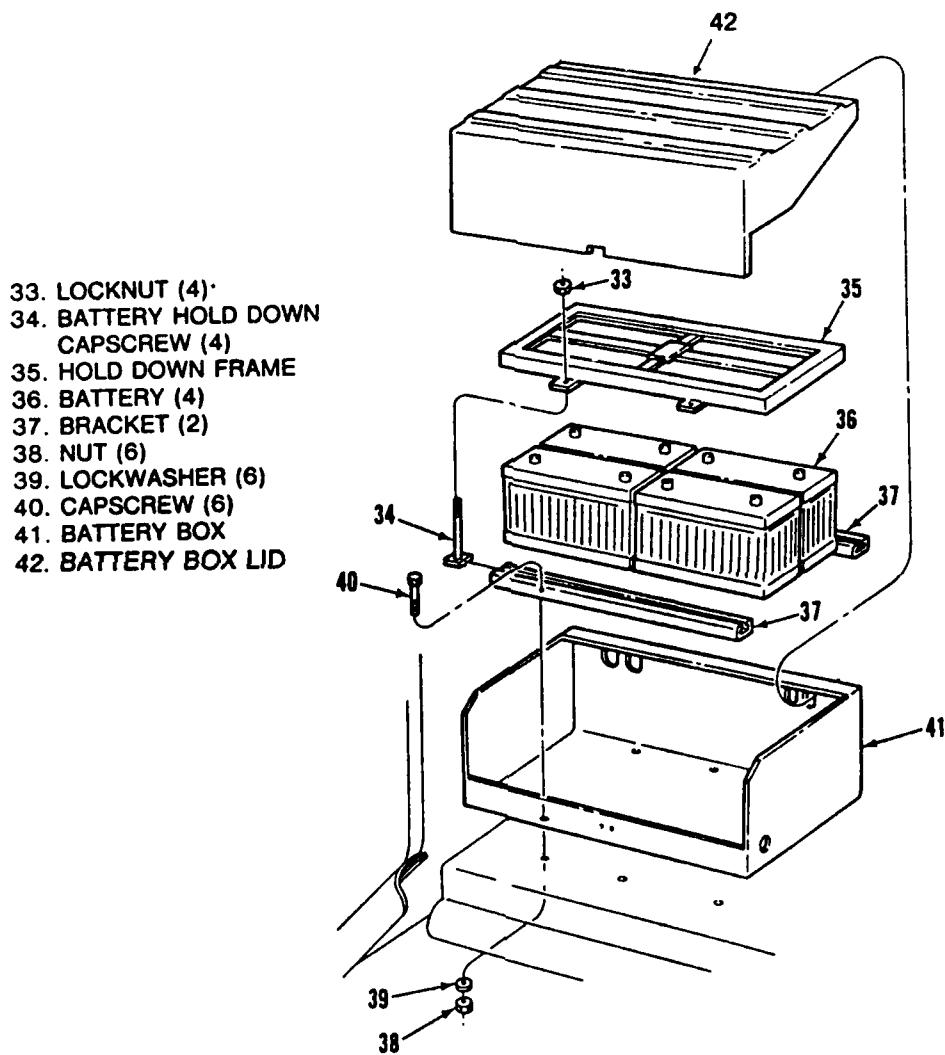


Figure 3. Diagram of Battery Box Assembly.

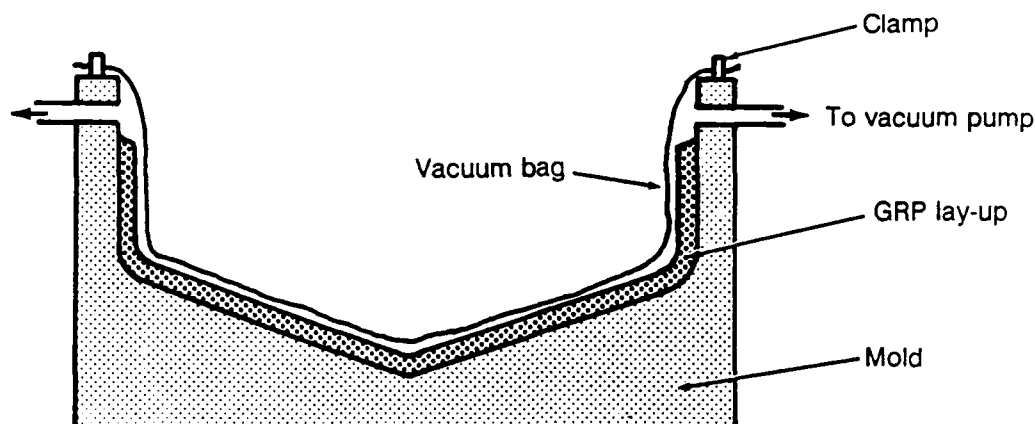


Figure 4. Vacuum Bag Molding Process.

MIL-R-7575C, Low-Pressure Laminating Polyester Resin, covered the polyesters and MIL-R-9300B, Low-Pressure Laminating Epoxy Resin, covered the epoxies; however, no military specification was identified for the vinyl esters. At this point it was decided to eliminate the vinyl-ester resins even though they exhibit good mechanical strength and chemical resistance properties, respectively. Therefore, the properties of the polyester and epoxy-resin systems were compared to select the composite matrix material. The criteria examined in the study included chemical resistance, mechanical strength, and cost.

Table 1⁷ lists chemical resistance data for typical epoxy and unsaturated polyester resins, respectively. Table 1 is composed of two different sections. The upper section lists general chemical resistance data for the polymers in typical corrosive environments, while the lower section lists resistance data for these resins in specific chemicals. As indicated in Table 1, the unsaturated polyesters are generally more susceptible to chemical attack by nonoxidizing acids, aqueous alkalis, polar solvents, nonpolar solvents, and water at the elevated temperature (65°C) than are epoxy resins. Also, epoxy resins exhibit superior chemical resistance compared with polyesters in dilute solutions of sulfuric acid (1-50%) at the higher temperature (65°C).

A comparison of the mechanical properties was performed based on data contained in MIL-R-7575C, Low-Pressure Laminating Polyester Resin, and MIL-R-9300B, Low-Pressure Laminating Epoxy Resin. These specifications revealed that the epoxies have higher flexural strength at room temperature compared with polyesters. Therefore, the epoxies were selected over the polyesters for this application because of their better chemical resistance properties and higher mechanical strength characteristics despite a slightly higher material cost.

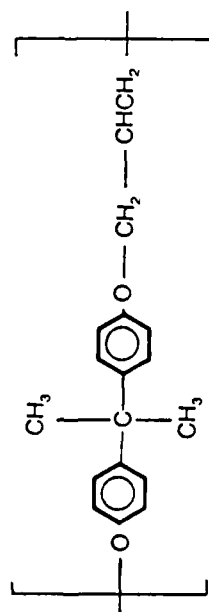
The specific epoxy resin system was selected based on fabrication considerations and also to meet the requirements specified in MIL-R-9300B, Low-Pressure Laminating Epoxy Resin. The specific resin system selected was Epon 828 with catalyst U (commercially available from Shell Chemical Company), which is a diglycidyl ether of bisphenol A (DGEBA) epoxy resin with a diethylenetriamine (DTA) adduct curing agent. The chemical structures of DGEBA, DTA, and a typical aliphatic amine adduct are shown in Figure 5.

NADC-90006-60

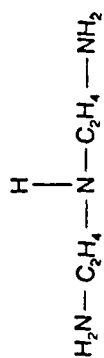
Table 1. Chemical Resistance Data for Typical Epoxy and Unsaturated Polyester Resins.

CHEMICAL	EPOXY		POLYESTERS (UNSATURATED)	
	25 °C (77 °F)	65 °C (149 °F)	25 °C (77 °F)	65 °C (149 °F)
Nonoxidizing acids (20% H ₂ SO ₄)	S	S	Q	Q
Oxidizing acids (10% HNO ₃)	U	U	U	U
Aqueous salt solution	S	S	S	S
Aqueous alkalis	S	S	U	U
Polar solvents	S	S	Q	U
Nonpolar solvents	S	Q	U	U
Water	S	S	S	Q
Benzene	Q	Q	U	U
Castor oil	S	Q	S	Q
Detergents (general)	S	S	Q	Q
Diesel fuel	S	Q	S	Q
Ethanol (1-95%)	S	Q	Q	U
Ethylene glycol	S	S	S	S
Freons	S	Q	S	Q
Gasoline	S	Q	S	Q
Heptane	S	Q	S	Q
Hexane	S	Q	Q	U
Isopropyl alcohol	S	U	Q	U
Kerosene	S	Q	S	Q
Mineral oil	S	S	S	Q
Naphtha	S	Q	S	Q
Octane	S	Q	S	Q
Soap	S	S	S	Q
Sulfuric acid (100%)	U	U	U	U
Sulfuric acid (70%)	S	Q	Q	U
Sulfuric acid (1-50%)	S	S	S	Q
Toluene	Q	Q	U	U
Xylene	Q	Q	U	U

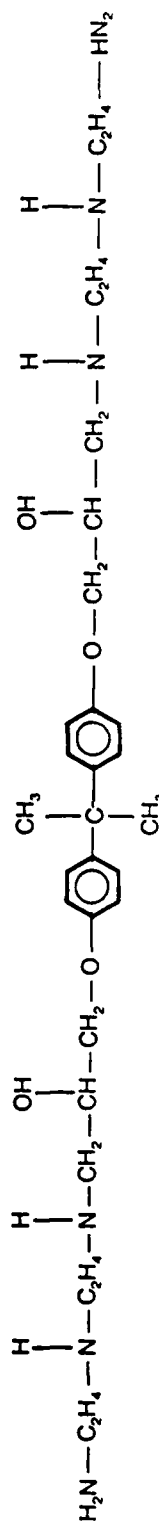
Legend: S = Satisfactory; Q = Questionable; U = Unsatisfactory.



Diglycidyl ether of bisphenol A (DGEBA) epoxy



Diethylenetriamine (DTA)



Typical amine adduct (DTA + DGEBA)

Figure 5. Chemical Structures of an Epoxy Resin and Curing Agents.

The Marine Corps also requested that the composite box have a green color through the resin, if possible, even though the box is to be coated with a green paint. The reason for this is to minimize the damage to the camouflage scheme if the paint is chipped or removed in a localized area. To accommodate this request, the final matrix resin comprised three parts of green dye mixed with 100 parts of epoxy resin (Epon 828), and 25.75 parts of the curing agent (Catalyst U) on a weight basis. The green dye is commercially available from Ferro, Inc. as pigment GV 36610 (olive drab/epoxy).

Glass fiber was selected over more exotic reinforcements (e.g., graphite fiber, and aramid fiber) due to its high flexural strength properties, good wet-out characteristics with low-pressure laminating resin systems, and low cost.^{8,9} The glass fiber reinforcement (E-glass) was selected to meet the requirements specified in MIL-C-9084C, Finished Glass Cloth for Resin Laminates. The particular fiberglass selected was a Class 2, Type VIII B (181-75DE) finished cloth, which is commercially available from Owens-Corning Fiberglas Corporation and is designated as ECDE 751/0.

DESIGN OF COMPOSITE BATTERY BOX

After the material system and fabrication process were selected, design of the battery box was initiated. In addition to the 113-kg (250-lb) static load requirement mentioned above, there was also a requirement that the composite box must interface with the existing composite battery box lid. Therefore, the starting point for the design of the composite battery box was to analyze the design of the existing steel one. The Marine Corps provided an actual steel battery box (part number 124374D, FSCM 45152, NSN 2510-01-208-6581) for dimensional measurements since the drawings were unattainable from the original manufacturer. The dimensions of the existing steel box are approximately 30.5 cm high by 76.2 cm wide by 48.3 cm deep and 0.279 cm thick (12" by 30" by 19" by 0.11") as shown in Figure 6. During this design phase it became apparent that a few changes were necessary to tailor the design of the battery box to be compatible with the material and process selected.

The first change deals with the locations of the circular holes designated as A1 and B1 in Figure 6 (on the back of the box). Typically, the vacuum bag molding process requires larger radius corners than those common to welded joints. Therefore, since these hole locations were not critical, they were moved 1 inch inward to permit a larger radius corner more compatible with the selected molding process.

The second change involves increasing the thickness of the composite box to 0.356 cm (0.14 inches) in order to provide the strength necessary to meet the 113-kg (250-lb) load requirement, while also maintaining an interface that mates with the existing lid.

These design changes did not impact the form, fit or function of the composite battery box or its installation on the Marine Corps MK-48 ground vehicle.

COMPOSITE FABRICATION PROCESS

The composite plaques and battery boxes were manufactured by Composite Horizons, Inc. (Covina, CA) using the fiberglass/epoxy material previously identified. The composite battery boxes were molded using a female composite tool fabricated from fiberglass/epoxy. The mold design concept permitted the top stiffening flanges of the battery box to be incorporated into a

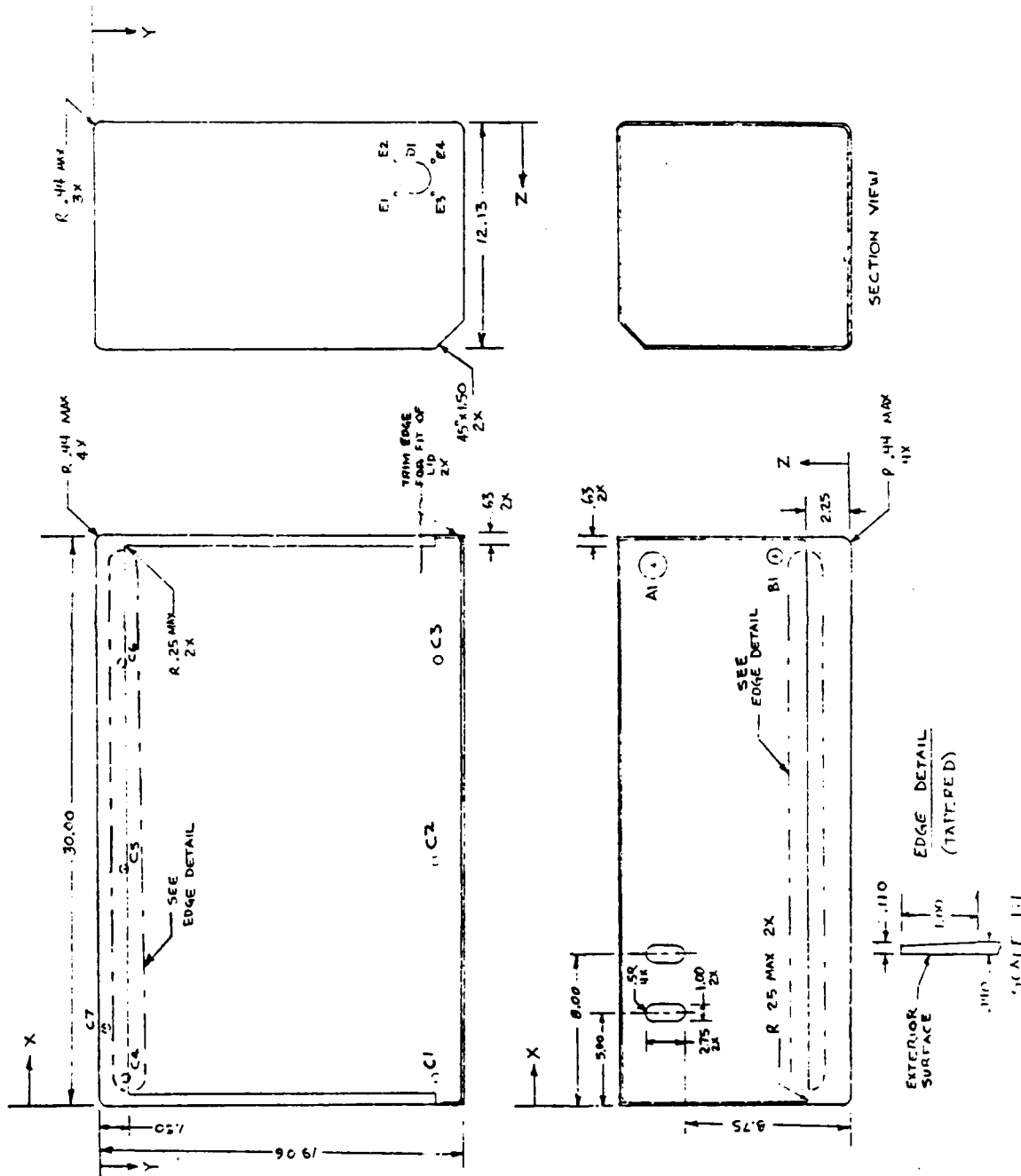


Figure 6. Detailed Drawing of Composite Battery Box.

monocoque design. The battery box design required that the tool be a two-part, split-type construction to allow for demolding of the part.

The fabrication process began by assembling the mold halves followed by the application of mold release to the polished surfaces. The layers of fiberglass cloth were then wet-out with the pigmented resin and hand layed-up until the desired 0.356-cm (0.140-inch) thickness was achieved. With the lay-up complete, the entire mold and lay-up were placed in a vacuum bag under 0.088 MPa of pressure (12.8 psi or 26 inches of mercury) and allowed to cure at room temperature for 8 hours. Note that a peel ply and bleeder cloth were utilized to control the resin flow during the cure. After the cure cycle, the part was demolded and the outside parting line (created between the two mold halves) was sanded flush. The flanges were then machined to the proper dimensions and all of the hole features were installed using the appropriate drill fixture.

EXPERIMENTAL PROCEDURE

All of the test specimens used for this work were machined from plaques consisting of 12 plies of fiberglass. The average plaque thickness was about 0.305 cm (0.120 inch).

DENSITY, FIBER VOLUME FRACTION, AND VOID CONTENT DETERMINATIONS

The density was measured in accordance with ASTM D792-66 (reapproved 1975), Method A1 using 2.54-cm by 2.54-cm (1" by 1") samples and deionized water as the immersion fluid. The fiber volume fraction was measured by igniting the 2.54-cm by 2.54-cm (1" by 1") specimens in accordance with ASTM D2584-68 (reapproved 1979). Void content of the composite was determined in accordance with ASTM D2734-70 (reapproved 1980). At least three replicates were tested for each of these measurements.

CHEMICAL RESISTANCE TESTING

Chemical resistance tests were performed at room temperature in accordance with ASTM D543-67 (reapproved 1978) using 2.54-cm wide by 7.62-cm long (1" by 3") test specimens. The samples were weighed before and after a 7-day chemical immersion, and weight change values were calculated. Additionally, after the 7-day immersion, the samples were conditioned for 7 days at room temperature and 50% relative humidity. Sample weights were taken again and compared with the initial weights to determine if there were any soluble constituents in the samples. The chemicals used for this test were a 30% sulfuric acid solution and distilled water.

MECHANICAL TESTING

Tensile testing of the selected composite material was performed in accordance with ASTM D3039-76 on a 10-Kip Instron test machine. A total of eight replicates were tested in the 0° direction at the room temperature/dry condition using 1.27-cm wide by 21.6-cm long (0.5" by 8.5") specimens. The failure stress was measured in the axis of loading. Fiberglass/epoxy end-tabs were adhesively bonded to the specimens to gradually move the load into the gage area. Additionally, a 90° fiber orientation on the bonded tab surface was used to match the 0°/90° orientation on the outer ply of the specimen to minimize adhesive bondline stresses. Furthermore, the end-tabs were also tapered to minimize the bondline stresses.

Flexure testing was performed in accordance with ASTM D790-81 at the room temperature/dry condition in the 0° direction using 2.54-cm by 7.62-cm (1" by 3") samples. A total of 11 replicates were tested. These tests were conducted using the four-point loading method at 1/3 points and a support span-to-thickness ratio of 16 to 1.

RESULTS AND DISCUSSION

DENSITY, FIBER VOLUME FRACTION, AND VOID CONTENT

The density of the composite material was determined to be 1.849 g/cc. To measure the fiber volume fraction, samples were weighed before and after ignition. The weight loss during ignition was 26.5%. Normally, this value is taken as the resin content and the remainder as the fiber content. However, the green dye added to the resin must be accounted for in this material.

It was learned from the manufacturer (Ferro, Inc.)¹⁰ that the green dye contained five different components. The weight percentage of each component and their respective densities are listed in Table 2.¹⁰ As indicated in Table 2, the dye consists of 50% epoxy and 50% metal oxides by weight. It is assumed that the 50% epoxy did burn and that the metal oxides did not burn or change in density during the ignition test. Therefore, the 26.5% that burned off is the weight percent matrix, and the remaining 73.5% by weight includes both the fiberglass and the four metal oxides.

Table 2. Weight Percent and Density Data for Green Dye.

COMPONENT	WEIGHT PERCENT	DENSITY (g/cc)
DGEBA Epoxy	50.0	1.16
Chromium Oxide	20.0	5.10
Iron Oxide	3.5	4.95
Magnesium Ferrite	11.5	4.40
Iron Oxide	15.0	4.05

To calculate the percent of fiberglass, it is necessary to recall the matrix formulation: 100 parts of DGEBA, 25.75 parts of curing agent, and three parts of green dye on a weight basis. Since the green dye is composed of 50% DGEBA, this equates to 1.5 parts of DGEBA. Therefore, the weight percentage of DGEBA in the dye may be computed as follows: $(26.5\%)(1.5/(1.5 + 100 + 25.75)) = 0.3\%$. Note that this is also equivalent to the weight percentage of metal oxides. Furthermore, the weight percentage of fiberglass is calculated as $100\% - 26.5\% - 0.3\% = 73.2\%$.

The theoretical density of the composite was calculated using the rule of mixtures. The density of the fiberglass used was 2.57 g/cc, according to the manufacturer (Owens-Corning Fiberglass Corp.).¹¹ The value used for the matrix density was 1.21.¹² The pigment densities used are listed in Table 2. Using this method, the theoretical density is calculated to be 1.983 g/cc. The volume percent of voids is computed as 6.8% using the following equation.

$$V_v = (100\%)(D_t - D_m)/(D_t) \quad (1)$$

where:

V_v = volume percent voids

Dt = theoretical density, and

Dm = measured density

CHEMICAL RESISTANCE PROPERTIES

The chemical resistance of the fiberglass/epoxy composite is a critical consideration that must be addressed if a material substitution is to occur. The composite must not dissolve or degrade upon exposure to common solvents or cleaning agents. In addition, exposure to battery acid (sulfuric acid) must not significantly change the performance or dimensions. After a 7-day immersion in 30% sulfuric acid, the samples gained an average of 0.8%. Upon conditioning at room temperature and 50% relative humidity, the weight gain decreased to 0.56%. The same test for distilled water produced weight gains of 0.29% and 0.031% respectively. These changes are not significant enough to affect performance. There is no loss of material, which indicates very little, if any, degradation is occurring. Upon drying in dynamic vacuum, the sulfuric acid samples returned approximately to their original weights. Total immersion in acid, although not likely in service, does not appear to degrade the performance of the battery box.

MECHANICAL PROPERTIES

The tensile strength of the composite material was determined to be 338 ± 13 MPa (49.0 ± 1.9 ksi). It was noted on most of the test specimens that the end-tabs had partially peeled from the composite material near the tip of the tapered region during testing. This may have introduced a small amount of error to the tensile strength values, but its effect is probably not significant. The tensile strength requirement specified in MIL-R-9300B is 331 MPa (48 ksi). Therefore, the measured tensile strength is slightly above this value despite the high volume fraction of voids (6.8%) present in the composite. This was no surprise since tensile strength is a fiber dominated property.

The flexure strength of the fiberglass/epoxy composite was determined to be 399 ± 15.8 MPa (57.9 ± 2.3 ksi). It is noted that 6 of the specimens failed in compression while the remaining 5 failed in tension. This indicates that the compressive strength of the composite is approximately the same as its tensile strength. The above statement is supported by the compressive and tensile strength requirements of 345 MPa (50 ksi) and 331 MPa (48 ksi), respectively, specified in MIL-R-9300B. However, it is also noted that the measured flexural strength of 399 MPa (57.9 ksi) is considerably lower than the 517 MPa (75 ksi) requirement specified in MIL-R-9300B. This was probably due to the high-volume fraction of voids (6.8%) present in the composite.

COMPOSITE BATTERY BOX EVALUATION

All composite battery boxes were inspected to assure both compliance with the dimensions shown in Figure 6 and overall quality workmanship. Each composite box was mated with the existing composite lid to assure that they interfaced properly. Additionally, a 113-kg (250-lb) load was applied to the center of the lid on the box/lid assembly as a performance test. Furthermore, the surface of each side of every box was A-scanned in two directions at 10.2-cm (4-inch) grid intervals to ensure that there were no areas with excessive amounts of internal porosity.

As a final quality check, each of the composite boxes were weighed. The average weight of a composite battery box was about 6.6 kg (14.6 lbs). The steel box provided by the Marine Corps weighed about 19.8 kg (43.7 lbs). Therefore, by replacing the steel box with the composite one, a 13.2-kg (29.1lb) weight savings may be achieved. Note that the composite box weighs about

NADC-90006-60

one-third that of the existing steel one. A photograph of both the existing steel battery box and the newly developed composite one is contained in Figure 7.

CONCLUSIONS

The void content was calculated to be 6.8%, which is acceptable based on the processing method employed (vacuum bag molding). There was no appreciable chemical degradation, and the mechanical properties met the requirements needed for the battery box. By replacing the steel battery box with the composite a weight savings of 13.2 kg (29.1 lbs) was achieved with the added advantage of significantly improved environmental durability.

RECOMMENDATIONS FOR FUTURE WORK

The major thrust of future work for the Marine Corps should be concentrated on replacing other metallic components on the MK-48 or any other ground vehicle with composites. In general, components requiring improved corrosion resistance, lighter weight, or enhanced solvent resistance should be targeted first since they will have the biggest payoffs. In the present battery box application there are also a few internal parts which may be converted from metal to composite. Specifically, the brackets, the hold down frame, and fastening assembly (shown in Figure 3) may be fabricated using composites. Hence, the acid resistance of the entire battery box assembly would be enhanced.

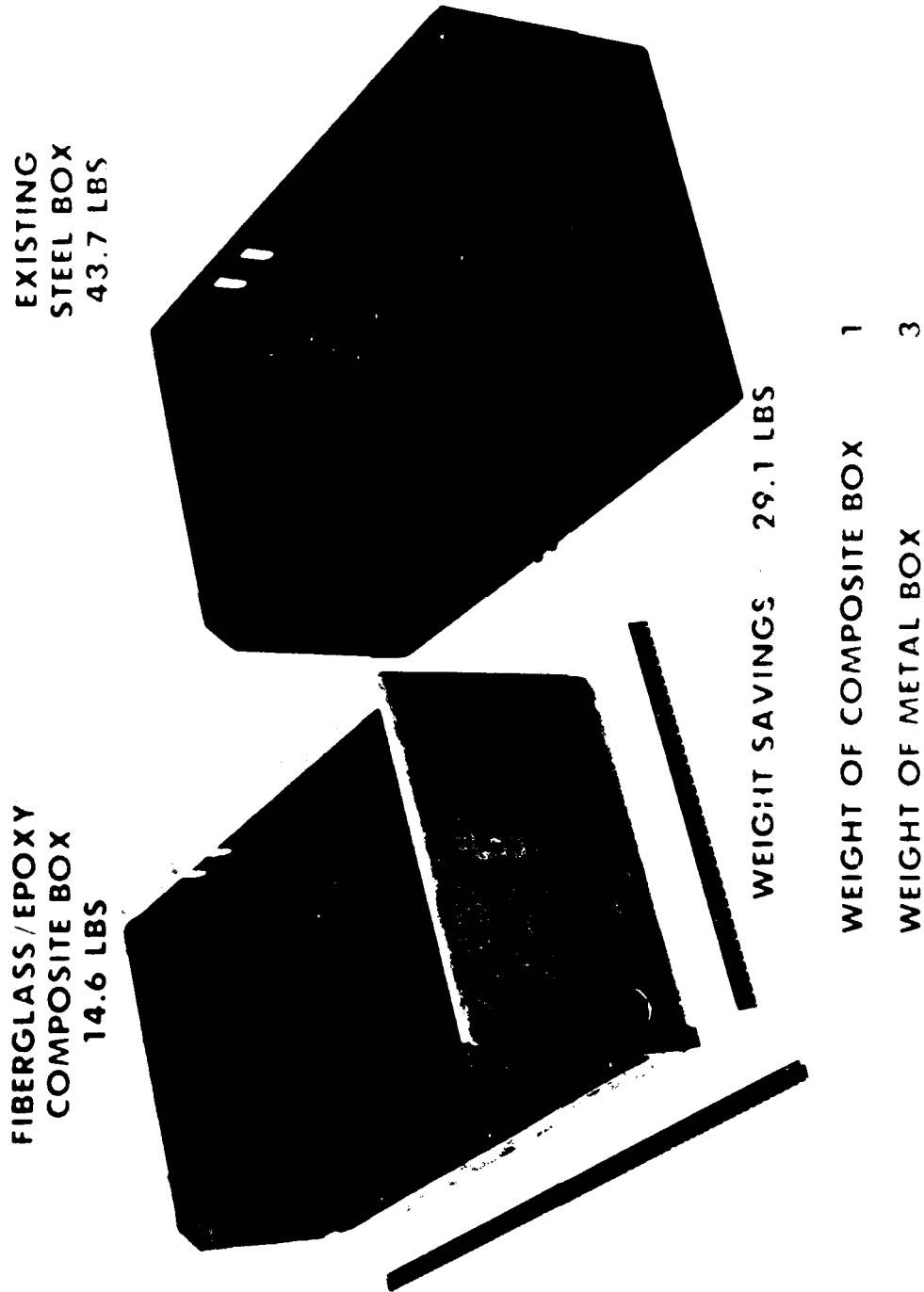


Figure 7. Photograph of Newly Developed Composite and Existing Steel Battery Boxes.

REFERENCES

1. R. G. Weatherhead, FRP Technology, Fibre Reinforced Resin Systems, Applied Science Publishers LTD, Chapter 4 (1980).
2. P. K. Mallick, Fiber-Reinforced Composites, Materials, Manufacturing, and Design, Marcel Dekker, Inc., Chapter (1988).
3. C. D. Dudgeon, "Polyester Resins", in Engineered Materials Handbook on Composites, ASM International, 1, 90-96 (1987).
4. C. A. May, "Epoxy Resins", in Engineered Materials Handbook on Composites, ASM International, 1, 66-77 (1987).
5. R. T. Dowd, "General Chemistry of Bisphenol A-Based Epoxy Resins", in Epoxy Resin Technology, Interscience Publishers, edited by P. F. Bruins, Chapter 1 (1968).
6. Major K. Williams, Private Communication (October 1988).
7. R. B. Seymour, Plastics vs. Corrosives, John Wiley & Sons, Chapter 14 (1982).
8. J. C. Leslie, "Properties and Performance Requirements", in Advanced Thermoset Composites, Industrial and Commercial Applications, Van Nostrand Reinhold Company, edited by J. M. Margolis, Chapter 3 (1986).
9. D. G. Mettes, "Glass Fibers", in Handbook of Fiberglass and Advanced Plastics Composites, Van Nostrand Reinhold Company, edited by G. Lubin, Chapter 7 (1969).
10. K. Rados, Private Communication (October 1989).
11. Epon Resin Structural Reference Manual, Appendix I, Table XXXI, 116.
12. D. Miller, Private Communication (October 1989).

THIS PAGE INTENTIONALLY LEFT BLANK

DISTRIBUTION LIST

NADC-90006-60

No. of Copies

Naval Air Systems Command.....	2
Washington, DC 20361	
Attn: D. Moore, AIR-5304	
D. Jamieson, AIR-41113E	
Naval Aviation Depot.....	2
NAS North Island	
San Diego, CA 92135	
Attn: H. D. Caldwell, Code 731	
M. J. Schmidt, Code 31213	
Naval Aviation Depot.....	1
Mail Stop No. 9	
MCAS Cherry Point, NC 28533-5030	
Attn: J. Fuss, Code 343	
Defense Technical Information Center.....	2
Cameron Station, Bldg. 5	
Alexandria, VA 23314	
Attn: DTIC-DDA-1	
Naval Air Force, U.S. Atlantic Fleet.....	1
NAS Norfolk	
Norfolk, VA 23511-5188	
Attn: G. Browne, AIRLANT 528	
Naval Air Force, U.S. Pacific Fleet.....	1
NAS North Island	
San Diego, CA 92135-5100	
Attn: B. Fusco, AIRPAC 7412	
Naval Aviation Engineering Service Unit.....	50
Philadelphia, PA 19112	
Attn: Code 018	
Distribution to all NAESU Corrosion Representatives	
Naval Aviation Depot.....	1
NAS, Norfolk, VA 23511	
Attn: J. Cole, Code 311	
Naval Aviation Depot.....	1
NAS, Jacksonville, FL 32212	
Attn: B. Beaman, Code 352	
Naval Aviation Depot.....	1
NAS, Pensacola, FL 32508	
Attn: M. W. Johnson, Code 321	